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Optimization of stiffened panels subjected to uniform lateral loading.

Sutton, William G.

Massachusetts Institute of Technology

OPTIMIZATION OF STIFFENED PANELS SUBJECTED TO UNIFORM LATERAL LOADING

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SUBJECTED TO
UNIFORM LATERAL LOADING

by

WILLIAM G. SUTTON

B.S. in Marine Engineering, U. S. Naval Academy (1970)

SUBMITTED IN PARTIAL FULFILLMENT OF THE

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June, 1971

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Submitted to the Department of Naval Architecture and Marine Engineering in partial fulfillment of the requirements for the degree of Master of Science in Naval Architecture and Marine Engineering.

ABSTRACT

The structural designer is continually faced with the problem of weight and cost optimization, especially in the area of ship design.

The purpose of this thesis was to develop an acceptable design method which integrates cost and weight in the optimization process of a typical ship structure.

The structure considered here consists of a laterally-loaded panel stiffened by angle stiffeners in one direction only. Six particular arrangements were used in the formulation of the design procedure. Stiffeners oriented either parallel to the long or short side of the plate for each of three stiffener end conditions, over a typical range of gross panel aspect ratios were studied. The costing method utilized by the Boston Naval Shipyard for similar structures was used to complete a cost analysis for all the individual designs investigated. With the use of both graphical and analytical procedures, a design method which enables the designer to investigate both weight and cost, and is acceptable for practically all rolled angle stiffeners, was developed.

This method gives the designer stiffener size, orientation, number and end condition, plus plating thickness for

the particular weight-cost relationship he prefers, and the particular design stresses and scantlings he is forced to deal with.

Thesis Supervisor: J. Harvey Evans

Title: Professor of Naval Architecture

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Also, thanks go to the Planning and Estimating Department of the Boston Naval Shipyard for assistance concerning cost analysis methods.

Finally, my deepest appreciation and sincere thanks to Shirley H. Price, whose nimble fingers and tremendous patience provided the typing of this thesis.

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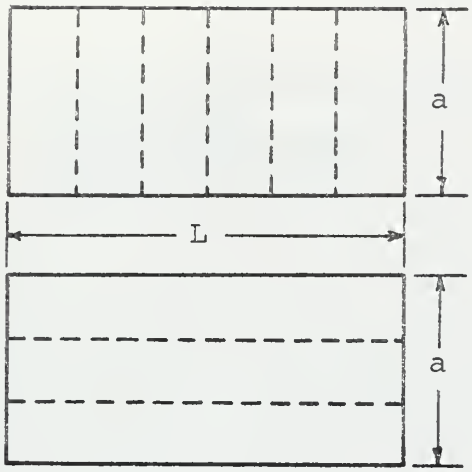
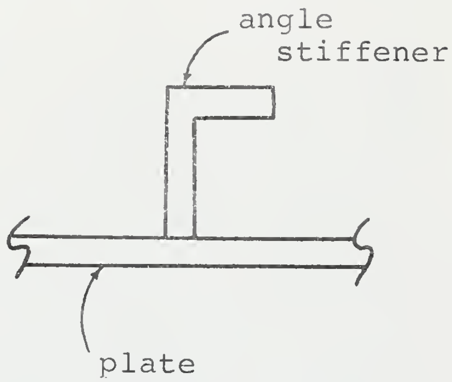




Symbol	Definition	Units
L	Dimension of long side of plate	ft.
a	Dimension of short side of plate	ft.
t	Plate thickness	in.
z	Section modulus of stiffener	in.^{3}
n	Number of panels (spaces) in gross plate	--
H	Head of salt water at 64 lbs./ft.^{3}	ft.
W_s	Weight of stiffener per foot	lbs./ft.
σ_p	Design bending stress of plating	k.s.i.
σ_s	Design bending stress of stiffener	k.s.i.
K	Plate factor	--
W_t	Total weight of structure	lbs.
W_p	Weight of plating	lbs./ft.^{2}
w	Unit load	lbs./ft.
ℓ	Dimension of length	ft.
M	Bending moment	ft./lbs.
ρ	Density	lbs./ft.
b	Stiffener spacing	ft.
W_{st}	Total weight of stiffeners	lbs.
W_b	Weight of brackets	lbs.
C_p	Plating cost	$
C_s	Stiffener cost	$
C_b	Bracket cost	$
C_m	Material cost	$
M.H.	Man-hours	hrs.
C_L	Labor cost	$
C_o	Cost of overhead	$

SYMBOLS (Continued)

Symbol	Definition	Units
C_{LO}	Cost of labor and overhead	$
C_t	Total cost	$
W_{tn}	Normalized weight	--
C_{tn}	Normalized cost	--

INTRODUCTION

Structural optimization, both in weight and cost, poses a definite problem which faces designers continuously. Less weight means more payload while complicated structures require greater construction costs. A superstructure assembly or a missile mount may require a least-weight design in a given situation, but what about hull plating? Minimum weight is definitely important but so is least cost. The most attractive design in practically all cases is a compromise between the two.

By placing appropriate emphasis on cost and weight, most designers would then like to be able to choose an acceptable solution. If least-weight expressions could be integrated into a detailed cost estimation procedure, a design method avoiding much trial and error might result. The purpose of this study is to produce such a design method for the structure described below.

A gross panel, laterally loaded, and stiffened by angle stiffeners is a structure widely known in ship design circles. Such assemblies as side shell plating and many types of bulkheads fall under this classification. Stiffener orientation here is not limited. They may be placed parallel to the short or long side of the plate.

In this study six basic arrangements are investigated, two stiffener orientations for each of three stiffener end

conditions. The three stiffener end conditions are as follows: (1) simply supported (hinged), (2) fixed without brackets (semi-fixed), and (3) fixed with brackets (bracketed).

Work in this area has been done by Harlander (Reference 1), who studied the least-weight applications of stiffeners oriented in one direction (parallel to the short side of the plate) with hinged or semi-fixed end conditions. His derivations of equations which optimized weight using a stress analysis provided a basis for this thesis. Because of the widely accepted use of stress analysis procedures in the design of shell plating, design stress will play the major role in this study.*

The development of a design method which acceptably integrates cost and weight in a simple, straightforward manner is the primary objective of this thesis.

*Work in deflection analysis for similar structures may be found in Reference 2.

PROCEDURE

A. STIFFENER SELECTION

The three main types of stiffeners used today in the construction of side shell plating and bulkheads are tee, angle, and flat bar stiffeners. In deriving least-weight equations for the gross panel structure, a mathematical expression for stiffener weight in terms of some variable, which would produce weight values for the stiffeners approximating actual values, is desirable. As the procedure for the derivation of stiffener weight as a function of section modulus has already been developed by Harlander, it was determined here that his equation would be used.

$$W_s = -.0114z^2 + 1.035\ z + 2.50$$

Harlander developed the "weight per foot" equation for angle stiffeners by polynomial curve fitting. He used the values reproduced in Figure 7 of the Appendix. Further investigation revealed that this equation is elliptical in nature, thereby placing limitations on the section moduli for which it is acceptable. Limits therefore must be placed on the size stiffener for which the derived least-weight expression can be utilized. By locating the maximum point in the equation, it was determined that only stiffeners up to a section modulus of 45.4 in.^{3} may be used in the derived least-weight expressions. This covers approximately the entire range of rolled angle stiffeners up

to a web height of eight inches. However, this does not entirely limit the design method developed herein, as will be shown later.

Each type of stiffener may be handled separately in studies similar to this by developing a weight-per-foot expression for the class stiffener investigated. Time and convenience, however, dictated the use of angle stiffeners here.

B. STIFFENER END CONDITION SELECTION

Because previous work had been done in the simply-supported and fixed-without-brackets areas these two end conditions showed much potential for expansion into this study. Bracketed stiffeners were then chosen in order to complete a general overlook analagous to all the methods presently employed in ship construction.

Using simple beam theory, a series of equations for section modulus as a function of salt water head, gross panel scantlings, number of stiffener spaces, and stiffener design stress were developed.

For the hinged condition, the standard moment equation, $M = \frac{W\ell^2}{8}$, was used to develop section modulus equations for both stiffeners oriented parallel to the long and short side of the plate.*

In the semi-fixed end condition, which may exist when

*See Appendix I-A and I-B.

the stiffeners are, say, continuous past the gross plate size, the moment equation becomes $M = \frac{W\ell^2}{12}$. Section modulus equations were developed here for the two orientations.*

Finally, the bracketed moment equation was found to be $M = \frac{W\ell^2}{24}$. This is due to the fact that the addition of the brackets causes the effective cross-sectional area of the stiffener to be greater at each end, thus decreasing the moment along the unsupported portion of the stiffener, yielding a smaller design moment for the same design stress in the bracketed condition. Section modulus equations were then developed for the two stiffener orientations.**

C. MINIMUM WEIGHT EQUATION DERIVATION

1. Case A: hinged stiffeners oriented parallel to the short side of the plate***
2. Case B: hinged stiffeners oriented parallel to the long side of the plate
3. Case C: semi-fixed stiffeners oriented parallel to the short side of the plate***
4. Case D: semi-fixed stiffeners oriented parallel to the long side of the plate
5. Case E: bracketed stiffeners oriented parallel to the short side of the plate

*See Appendix I-C and I-D.

**See Appendix I-E and I-F.

***The equations used for Cases A and C were obtained from Reference 1, page 16.

6. Case F: bracketed stiffeners oriented parallel to the long side of the plate

The existence of bracketing in Cases E and F required the derivation of an equation for bracket weight. Assuming that the brackets were cut from the stiffeners used in each case, a relationship of bracket weight as a function of stiffener weight was obtained by the method illustrated in Appendix II.

A general expression for the total weight of the structure was written as a function of the scantlings of the plate, the weight per foot of the stiffeners, and the number of stiffeners and/or brackets. The basic assumptions made were as follows: (1) only the bending stresses in the plate were considered, (2) each panel in the plate was considered separate with clamped edges, (3) the stiffeners would be 100 percent efficient, and (4) simple beam theory would govern stiffener stressing. By minimizing the number of panels (i.e., stiffeners), and by setting up parametric values to simplify the equations, a least-weight equation for each case was developed.*

As the parameters developed for use in the weight equations bore no physical significance and were dimensionally complicated, an unsuccessful attempt was made to non-dimensionalize the weight relationships. First the stiffeners used in the

*The method used was developed by Harlander. For a detailed derivation and additional assumptions, see Appendix I.

derivation of the stiffener weight equation were tested for geosimilarity. The results were negative. The parameters were then varied in an attempt to place physical significance on them, but the resulting complication made this approach worthless. Finally, weight per unit area of plating and stiffener weight per total weight were investigated by the manipulation of the weight equations, also producing negative results.

D. WEIGHT GRAPH CALCULATIONS

The need for a series of comparative least-weight values then arose for use in a detailed cost analysis. A range of gross panel aspect ratios from 1.0 to 4.0 were used with a salt water (ρ = 64.0 lbs./ft.^{3}) head of 20.0 ft. σ_p and σ_s were set at 33.0 k.s.i. and 27.0 k.s.i., respectively, and the long dimension of the plating was fixed at 12.0 feet. These values were chosen for both practicality and convenience. The above values were then used to calculate a series of weight characteristics for each case. (See Tables I, II, and III.) A graph of total weight versus aspect ratio was then made for further study (Figure 1).

E. METHOD OF COSTING

The first cost estimating method used was that illustrated in Reference 4. This method was very general and did not seem to serve any useful purpose except as a future means of comparison.

To obtain a realistic, detailed method to determine both material and labor cost for the least-weight structures studied, the Planning and Cost Estimating Department of the Boston Naval Shipyard was consulted. The result was a rather straightforward method which has been summarized in Appendix III. The only assumption here was that the plating, stiffeners, and brackets already sized by the least-weight calculations were, in fact, available as off-the-shelf items. A complete cost analysis was run again, using this detailed method, on each of the structural arrangements, and the results tabulated in Tables V, VI, and VII.

F. COST GRAPH DEVELOPMENT

In order that some comparison might be made between cost and weight for use in the design method, several graphs along cost lines were developed. First, a graph of total cost versus aspect ratio was made (Figure 2). To somewhat authenticate the practicality of the cost calculations a graph of labor cost versus material cost was made (Figure 3). Finally, to develop a comparative graph based on both cost and weight in an effort to generalize, the material weight figures from the least-weight calculations and the total cost calculations were normalized about the hinged-end, parallel to the short side, aspect ratio 1.0 case, resulting in Table VIII and Figure 4.

G. "t/z" RELATIONSHIP

By dividing the derived expression for plating thickness, t, by the derived expression for stiffener section modulus, z, it was discovered that this relationship is independent of the number of stiffeners. In fact, t/z is a function only of head, length of stiffener, plating design stress, and stiffener design stress. This is a very useful expression when dealing in areas where the least-weight values for t and z are impossible to reach practically. By the use of this relationship one can avoid the least-weight equations, which are limited by a certain value of z. As will be shown later, in using this approach the least-weight solution cannot be reached but it can be approximated as close as is practically possible.

RESULTS

The results of this thesis are given in the form of curves in Figures 1, 2, 3, 4, and 5, and two design methods for the structures studied herein.

Figure 1: total weight versus aspect ratio

Figure 2: total cost versus aspect ratio

Figure 3: labor cost versus material cost

Figure 4: normalized weight versus normalized cost

Figure 5: normalized weight versus aspect ratio

For the design methods the following information must be given:

1. Length and width of plate (L, a)
2. Head of salt water at $\rho = 64.0$ lbs./ft.^{3} (H)
3. Design stresses for plating and stiffeners (σ_p, σ_s)

I. LEAST-WEIGHT DESIGN METHOD FOR LATERALLY LOADED PLATING STIFFENED BY ANGLE STIFFENERS

PROCEDURE:

1. Enter Figure 5 to determine orientation and end condition of stiffeners. (Figure 5 can be used only when $H \simeq 20.0$ feet, $\sigma_p \simeq 33.0$ k.s.i., and $\sigma_s \simeq 27.0$ k.s.i.)
2. Choose appropriate least-weight equations from Appendix I and solve for n.
3. Solve for t and z. ($z \leq 45.4$ in.^{3})

4. Use appropriate total weight equation from Appendix I and solve for material weights.

5. Use costing method outlined in Appendix III to determine various costs.

II. WEIGHT-COST OPTIMIZATIONAL DESIGN METHOD FOR LATERALLY LOADED PLATING STIFFENED BY ANGLE STIFFENERS

PROCEDURE:*

1. Enter Figure 4 to determine orientation and end condition of stiffeners. (Emphasis on cost or weight determined by personal preference. Figure 4 can be used only when $H \simeq 20$, $\sigma_p \simeq 33$, and $\sigma_s \simeq 27$.)

2. Solve appropriate "t/z" value (from Appendix I).

3. Use appropriate least-weight equation from Appendix I to solve for the least-weight value of n.

4. Use the least-weight value of n to solve for least-weight t, and z. ($z \leq 45.4$ in.^{3})

5. Determine feasible value of t closest to the least-weight value.

6. Use appropriate equation for t to solve for new value of n.

7. Use "t/z" to solve for new z value.

8. Determine stiffener size to be used by taking available stiffener closest in section modulus to the calculated value.

*See Sample Problem for illustration of optimization procedure.

9. Use t, z, n, L, a, and W_s in the appropriate weight equation (from Appendix I) to solve for material weights. (If z final $\leq$ 45.4 in.^{3} one may use $W_s = -.0114z^2 + 1.035z + 2.50$. If z > 45.4 in.^{3} use the book value for W_s including the effective area 30t.)

10. Use the costing method outlined in Appendix III to determine various costs.

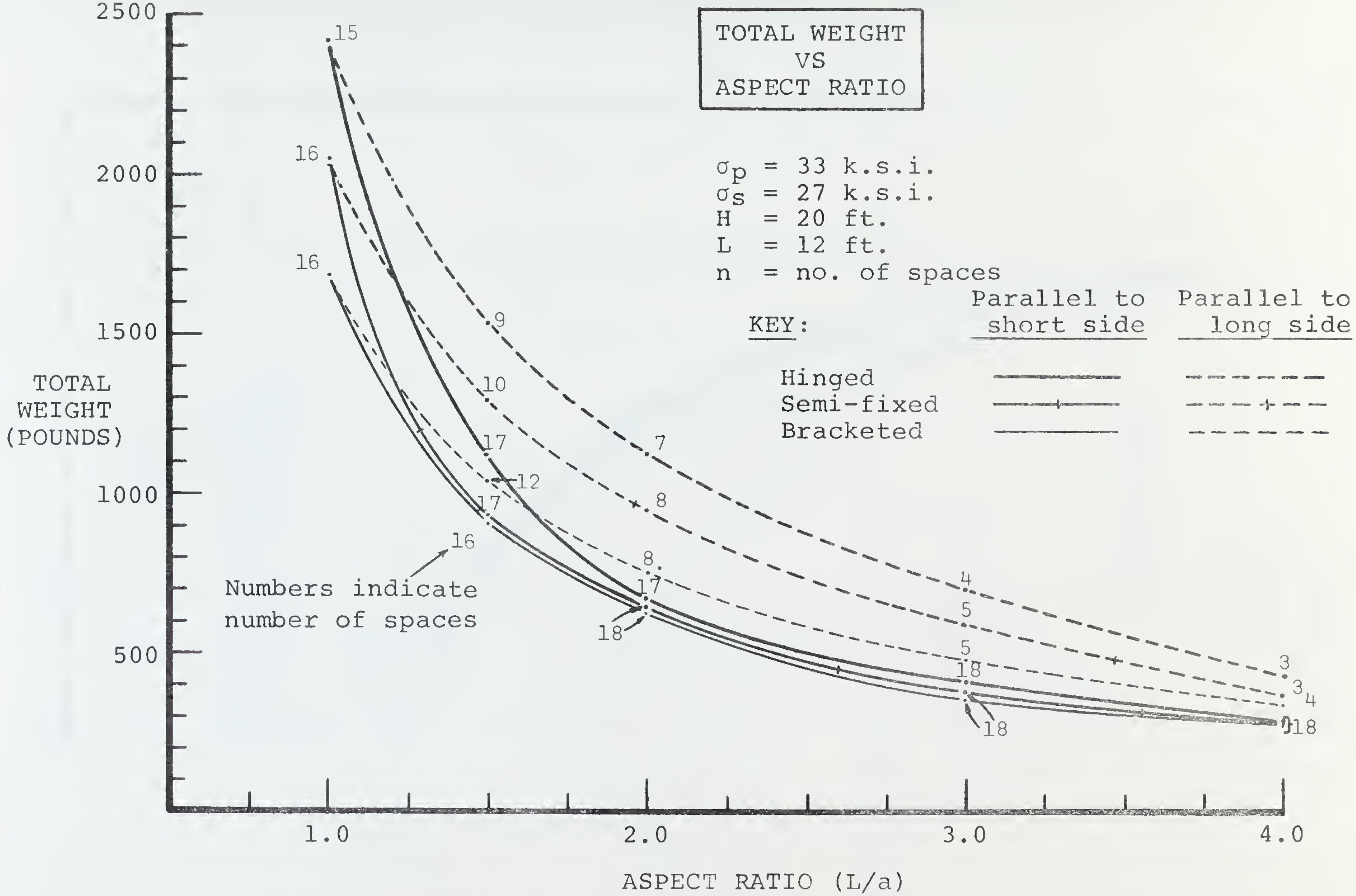

TOTAL WEIGHT
VS
ASPECT RATIO
σ_p = 33 k.s.i.
σ_s = 27 k.s.i.
H = 20 ft.
L = 12 ft.
n = no. of spaces
KEY:
Parallel to short side
Parallel to long side
Hinged
Semi-fixed
Bracketed
TOTAL WEIGHT (POUNDS)
2500
2000
1500
1000
500
1.0
2.0
3.0
4.0
ASPECT RATIO (L/a)
Numbers indicate number of spaces
15
16
16
9
10
17
12
17
16
7
8
8
17
18
4
5
5
18
18
3
3
4
18

Figure 1

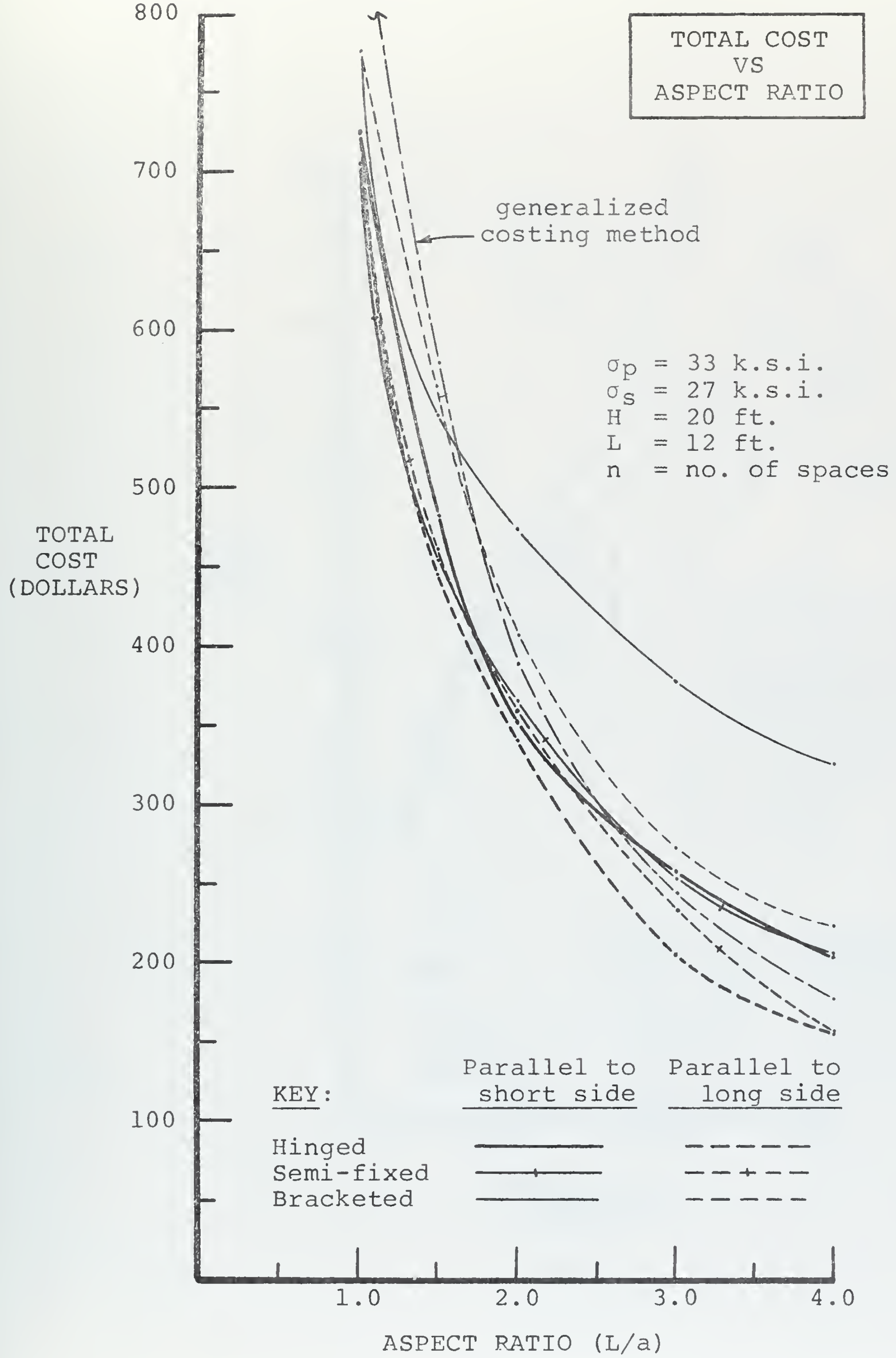

TOTAL COST
VS
ASPECT RATIO
800
700
600
500
400
300
200
100
TOTAL
COST
(DOLLARS)
generalized
costing method
σp = 33 k.s.i.
σs = 27 k.s.i.
H = 20 ft.
L = 12 ft.
n = no. of spaces
KEY:
Parallel to
short side
Parallel to
long side
Hinged
Semi-fixed
Bracketed
1.0
2.0
3.0
4.0
ASPECT RATIO (L/a)

Figure 2

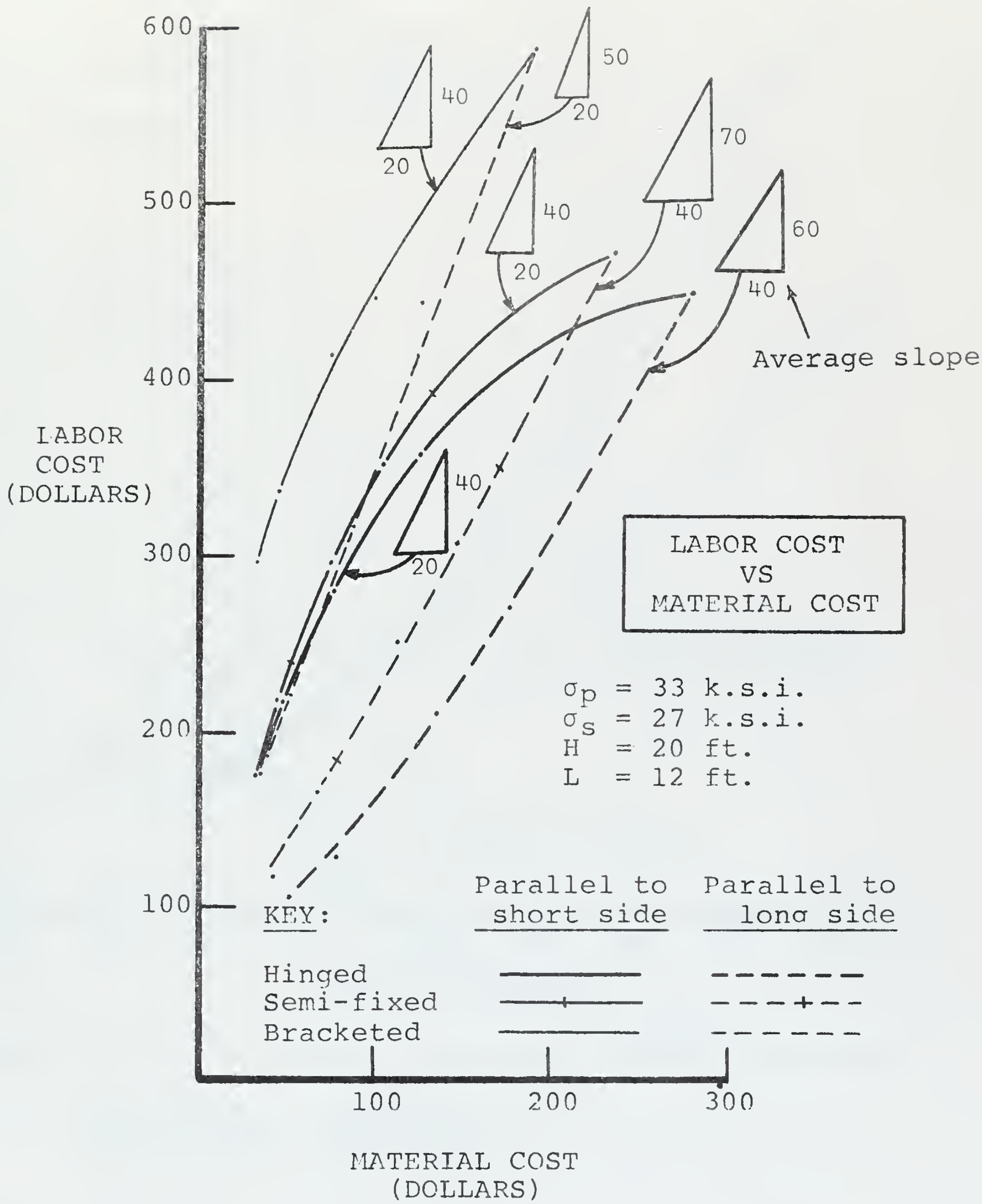
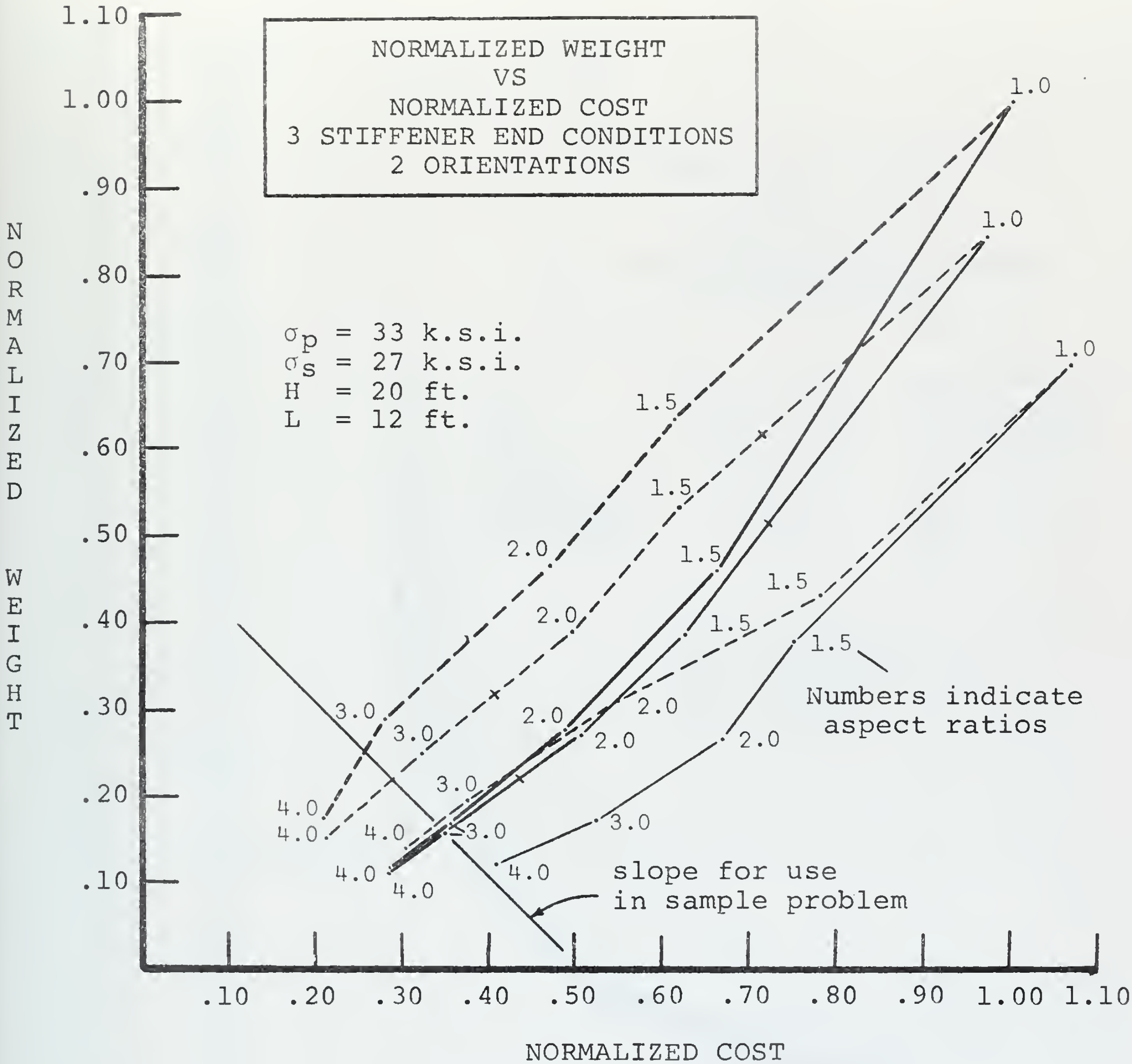

600
500
400
300
200
100
LABOR
COST
(DOLLARS)
40
20
50
20
70
40
40
20
60
40
Average slope
40
20
LABOR COST
VS
MATERIAL COST
σ_p = 33 k.s.i.
σ_s = 27 k.s.i.
H = 20 ft.
L = 12 ft.
KEY:
Parallel to short side
Parallel to long side
Hinged
Semi-fixed
Bracketed
100
200
300
MATERIAL COST
(DOLLARS)

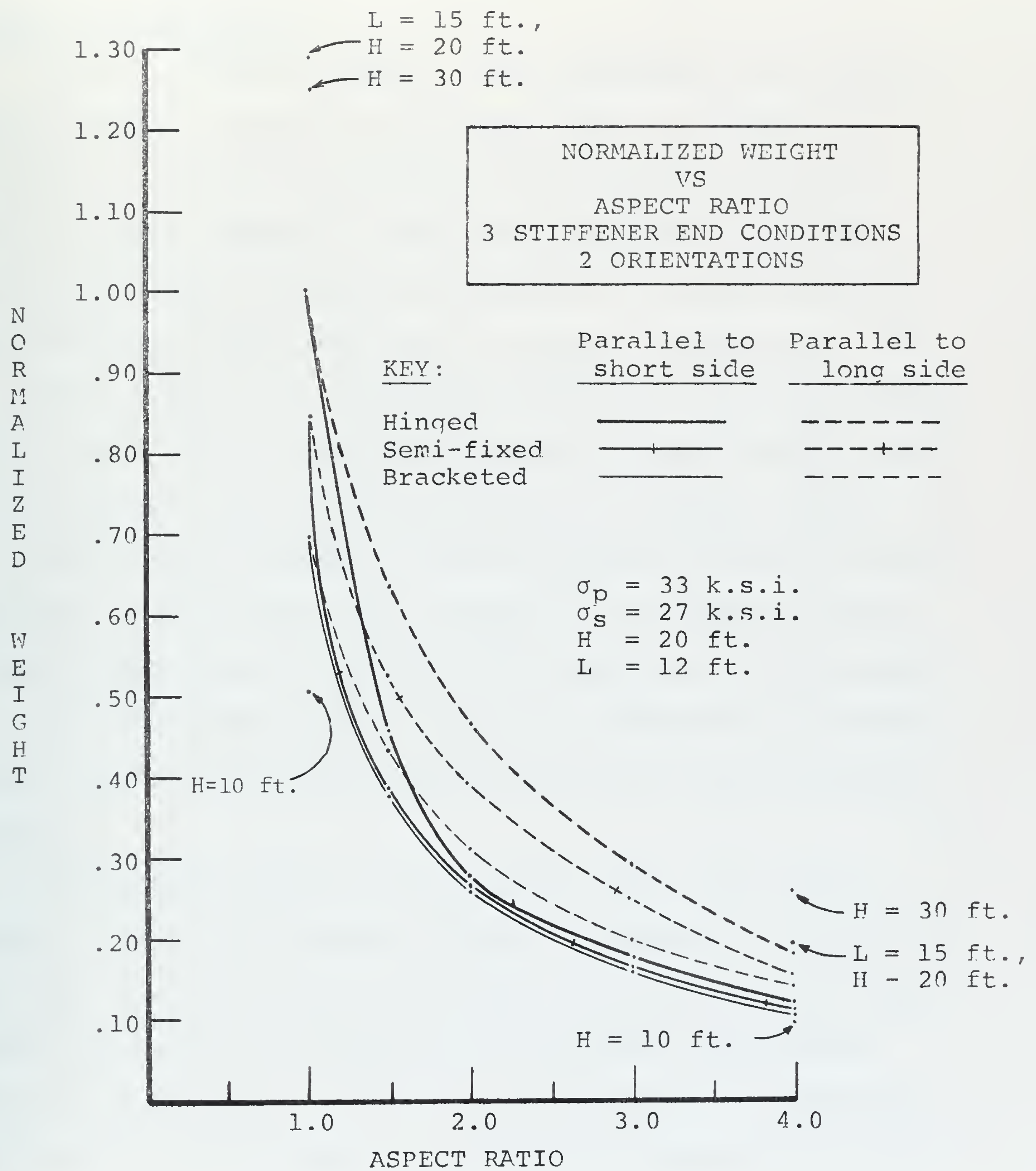
Figure 3



NOTE:
Normalized about $\frac{L}{a}$ = 1.0 end condition - simply supported

KEY:	Parallel to short side	Parallel to long side
Hinged	————	— — — —
Semi-fixed	——+——	— — + — —
Bracketed	————	– – – – –

Figure 4



NOTE:
Normalized about $\frac{L}{a}$ = 1.0 end condition - hinged

Figure 5

DISCUSSION OF RESULTS

FIGURE 1 AND FIGURE 5

As can be seen in Figure 1, the assemblies with stiffeners oriented parallel to the short side are always the lightest structures with aspect ratios greater than 1.65. This is a good defense of the usual procedure of placing stiffeners almost exclusively parallel to the short side of the stiffened plate when lateral loadings predominate. The bracketed assembly with stiffeners parallel to the short side of the plate was the lightest structure at each aspect ratio. The difference here can be attributed to stiffener weight. The design bending moment of the stiffeners in this case was decreased significantly (by a factor of 1/2 times the semi-fixed bending moment) because of the addition of the brackets. Even with the added bracket weight, the decrease in stiffener section modulus was good enough to yield the lowest material weights.

The plating weights at each aspect ratio were not as varied as were the stiffener weights (stiffeners parallel to the short side), therefore the basic weight differences were caused mostly by the variations in stiffener requirements. The plating thickness, which is the major factor in determining plating weight, given the gross panel dimensions, is itself determined by an equation of the form:

$$t = .179\left(\frac{L}{n}\right)\sqrt{\frac{H}{\sigma_p}}$$

In the calculations which produced these graphs, the long dimension of the gross panel, L, the head, H, and the design plating stress, σ_p, were all held constant. The slight variation in n, which also depended on these values, therefore caused the plating thicknesses to be relatively constant over a given aspect ratio when the stiffeners were oriented parallel to the short side.

In the cases where the stiffeners were oriented parallel to the long side, the variation in "a" (short-side gross panel dimension), produced varied plating thicknesses and therefore wide variations in plating weight. This variation in "a" also produced a greater range in the number of stiffeners for the parallel to the long side equations.*

The variation of H (head of salt water) has a great effect on n and therefore z. For example, a 10.0 foot decrease in H in Case A, aspect ratio 1.0 causes a six percent increase in plating weight and a 46 percent decrease in stiffener weight. Head variations in both the parallel to the long side and short side cases will result in great changes in the weight and cost figures. An overall investigation revealed that the relative positions of the various cases will remain constant because of the "linearity" of H and its effect on the stiffener

*See Appendix I for the "a" effects on n, i.e., number of stiffeners.

weights within the calculations (i.e., $z = .032 \frac{HLa^2}{n\sigma_s}$).

The long side arrangements were basically heavier in all cases due to the fact that the stiffeners required were very much larger in section modulus than those required in the short side arrangement. While there was a smaller number of long side stiffeners required, the great margin in section modulus caused extremely higher stiffener weights.*

FIGURE 2 AND FIGURE 3

Total cost prescribed by the method illustrated in Appendix III was plotted here versus aspect ratio and, in fact, revealed the expected. The lightest condition was also the costliest. This is due to the fact that as structures become more and more complicated (i.e., addition of brackets) the fabrication and construction costs become greater. Conversely, the heaviest structure is also the cheapest due to its simplicity of design.

In order to authenticate this particular costing procedure Figure 3 was developed. Its general purpose is to compare labor cost and material cost without the well-known "political fudge factor." Many theories have been developed and disproved along these lines, and by keeping in mind the realities of the subject, a general authentication of this costing procedure can be made. By graphically determining the average slopes

*See Tables I, II, and III.

of the six curves, a factor of two was determined to be the approximate ratio of labor cost (plus overhead) to material cost for the arrangements with stiffeners parallel to the short side of the plate and factors of 1.5 to 2.5 for the arrangements with stiffeners parallel to the long side of the plate.

A generalized method for estimating cost, illustrated in a paper by Evans and Khoushy (Reference 4), was used also to determine the practicality of the detailed method summarized in Appendix III. For the two cases with hinged stiffeners the cost figures were approximately the same over aspect ratios 2.0 to 4.0. At an aspect ratio of 1.0 the general method produced cost figures in excess of 20 percent greater than those of the detailed method. In the two semi-fixed arrangements the above was also true. In the bracketed cases, however, a closer relationship existed on all aspect ratios, the largest variation being again at aspect ratio 1.0, where the general figures were approximately twelve percent greater than the cost figures produced by the detailed method. The differences in the cost figures produced by the two methods can be attributed to the gross generalizations of one method and the detailed scrutiny of the other method. The similarity that did exist is remarkable when one studies the differences in approach of the two methods in actually estimating cost.

FIGURE 4

How does one relate cost and weight in order to choose an orientation and a stiffener end condition? Due to the dimensional complexities of the problem a normalized curve was the obvious choice. In Figure 4 all the weight and cost values for each structural arrangement were normalized about the simplest structure (hinged-end stiffeners, aspect ratio 1.0). The first limitation to be placed on this graph is the fact that it is for only one head of salt water and only the least-weight solutions. However, by realizing the characteristics aforementioned concerning these limitations, a fairly accurate conclusion involving other heads and stresses may be made. Due to the lack of an operations analysis study of how much emphasis should be placed on cost and weight, this graph provides the logical stepping-off point for the design method. When other than optimum weight values for n are studied the results show the usefulness of the graph. Variations of n both greater and less than optimum produce slight variations in cost and definite increases in weight. (See Figure 6.)

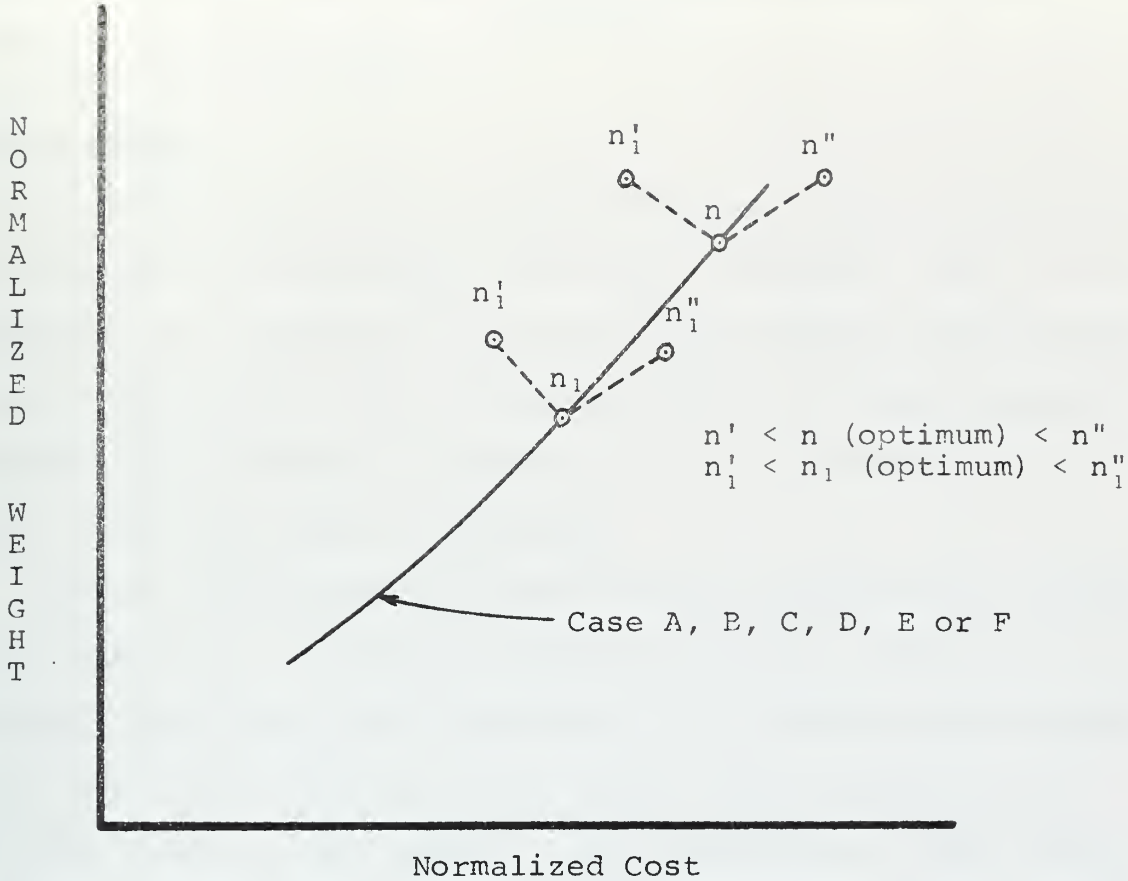


Figure 6

The optimum weight solution is therefore the logical choice for cost comparison. The individual designer's preference as to the numerical percentage reliance on weight and the same for cost can be used in this figure by applying the appropriate slope. As he moves this slope up and to the right, the logical arrangement based on his preference can be obtained when the aspect ratio of his choice intersects this moving

slope, no matter what the structural configuration of end condition and orientation.

DESIGN METHOD

In each usage of the methods the least-weight value for n and t should be striven for. The "t/z" constant, which is independent of n, becomes a handy tool when feasibility dictates a variance from the least-weight solution. In every instance, however, upon choosing a practical value for either t or z, a new value for n must be obtained.

Due to the elliptical nature of the expression for stiffener weights as a function of section modulus, there exists a necessary limit as to the value of z to be used in the optimum weight solution. Only stiffeners with section moduli up to 45.4 $in.^3$ may be used; however, this represents a large majority of the rolled angle stiffeners on the market today. (Up to a web depth of approximately 8.0 inches.) To avoid this limitation, one can calculate the "t/z" constant, the n by the use of the appropriate "t" equation. A value for stiffener weight per foot must then be obtained elsewhere to be used in the total weight equation.

If the procedures listed herein are followed, and the minor limitations observed, an effective design of a laterally-loaded, stiffened panel can be easily obtained.

CONCLUSIONS

1. The least-weight design limitation is for stiffener section moduli less than or equal to 45.4 in.^{3}. This fact, however, may be avoided if the "t/z" relationship is used vice the derived least-weight equations.

2. Stiffeners oriented parallel to the short side of the plate yield, in general, the lightest solution (1.0 $\leq$ aspect ratio $\leq$ 4.0).

3. The lightest design between aspect ratio 1.65 and 4.0 exists when the stiffeners are bracketed and oriented parallel to the short side of the plate.

4. Salt water head variation greatly effects weight and cost, but results in parallel relationships, completely extrapolative.

5. The costing method used in this thesis is completely reasonable within certain realistic assumptions.

6. Variation of the number of stiffeners, n, from the least-weight value increases weight significantly, but because cost is only slightly effected, the least-weight solution is the best to integrate with cost in the optimization procedure.

7. The values n and t are of primary importance in the optimum design and should be fixed in value to approximate those values obtained from the least-weight design.

RECOMMENDATIONS

The three major stiffener end conditions for both orientations have been studied in this thesis. Expansion of this study into variations in end conditions would definitely add to the design method developed here. To increase "scope" would be the best recommendation. Completing the work done here but using various salt water heads and design stresses would greatly add to the scope. Various values of n other than optimum weight would be of great benefit in the utilization of a similar normalized weight-cost graph. General expressions for stiffener weight in terms of section modulus for all three basic stiffener types could dispose of the size and type limitation experienced in this design method.

The most attractive area of continuation would be that of computer programming. A program to utilize various salt water heads, values of n, different stiffener types, and more end conditions could be written. This would result in a complete set of design curves along the lines of the ones explored here, which could rid the designer of all "trial and error" and guesswork in designing a structure of this type. Also, by taking into consideration in-plane tension and compression, this method could be used for a greater number of stiffened panel assemblies.

Expansion in any one or all of the above directions would result in a more completely useful design method.

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APPENDIX I

DERIVATION OF LEAST-WEIGHT EQUATIONS

APPENDIX I

DERIVATION OF EXPRESSION FOR MINIMUM TOTAL WEIGHT FOR STIFFENED PLATING SUBJECTED TO UNIFORM HYDROSTATIC LOAD*

ASSUME: Plate edges clamped

NOTATION:

W_t = total weight of plating and stiffeners - Lbs.

W_s = weight of stiffeners - Lbs./Ft.

W_p = weight of plating - Lbs./Ft.^{2}

H = head of salt water - Ft.

σ_s = design bending stress (stiffeners) - k.s.i.

σ_p = design bending stress (plating) - k.s.i.

z = section modulus of stiffener - In.^{3}

t = plate thickness - In.

n = number of panels

ρ = density of salt water - Lbs./Ft.^{3}

L = plate dimension parallel to long side - Ft.

M = bending moment - Ft.-Lbs.

a = plate dimension parallel to short side - Ft.

W = unit load - Lbs./Ft.

ℓ = length - Ft.

STIFFENER WEIGHT:**

$$W_s = -.0114\ z^2 + 1.035\ z + 2.50$$

A. STIFFENERS WITH HINGED ENDS ORIENTED PARALLEL TO THE SHORT SIDE OF THE PLATE

TOTAL WEIGHT:

$$W_t = aLW_p + (n-1)\ a\ W_s$$

$$W_t = 40.8\ aLt + (n-1)a[-.0114z^2 + 1.035z + 2.50]$$

ASSUMING SIMPLE BEAM THEORY IT CAN BE SHOWN THAT:

1. For the plating:

   From $\sigma_p = 1/2\ K\rho H\ (b/t)$ where $b = (L/n)$, $K = 1.0$

   $t = .179\ (L/n)\sqrt{H/\sigma_p}$

2. For the stiffeners:

   From $\sigma_s = \frac{M}{z}$ where $M = \frac{W\ell^2}{12}$ (W = unit load)

   $z = .096\ (HLa^2/n\sigma_s)$

3. $\frac{t}{z} = \frac{1.865}{a^2\sqrt{H}}\ (\frac{\sigma_s}{\sqrt{\sigma_p}})$, therefore,

$$W_t = 7.3(L^2a/n)\sqrt{H/\sigma_p} + (n-1)a[(-1.05 \times 10^{-4}) \times (HLa^2/\sigma_s n)^2 + .0994\ (HLa^2/\sigma_s n) + 2.50]$$

Let $A = L^2\sqrt{H/\sigma_p}$ and $B = HLa^2/\sigma_s$

DIFFERENTIATING W_t WITH RESPECT TO n AND SETTING EQUAL TO ZERO (MINIMIZE WEIGHT):

$$A = .342n^2 + (1.44 \times 10^{-5})\ (1-2/n)B^2 + (1.36 \times 10^{-2})B$$

and

$$W_t = aL40.8t + (n-1)\ a[-.0114z^2 + 1.035z + 2.50]$$

B. STIFFENERS WITH HINGED ENDS ORIENTED PARALLEL TO THE LONG SIDE OF THE PLATE

TOTAL WEIGHT:

$$W_t = aLWp + (n-1)\ LW_s$$

USING SIMILAR METHODS AS IN "A" ABOVE:

1. For the plating:

$$t = .179\ (a/n)\sqrt{H/\sigma p}$$

2. For the stiffeners:

$$z = .096\ (HaL^2/n\sigma_s)$$

3. $$\frac{t}{z} = \frac{1.865}{L^2\sqrt{H}}\ \left(\frac{\sigma_s}{\sqrt{\sigma p}}\right)$$

Let $C = a^2\sqrt{H/\sigma p}$ and $D = HaL^2/\sigma_s$

(parameters for use in weight equation)

$$C = .342n^2 + (1.44 \times 10^{-5})D^2(1- \frac{2}{n}) + (1.36 \times 10^{-2})D$$

and

$$W_t = aL40.8t + (n-1)L[-.0114z^2 + 1.035z + 2.50]$$

C. STIFFENERS WITH SEMI-FIXED ENDS ORIENTED PARALLEL TO THE SHORT SIDE OF THE PLATE

USING SIMILAR METHODS:

1. For the plating:

$$t = .179\ (L/n)\sqrt{H/\sigma p}$$

2. For the stiffeners:

$$z = .064\ (HLa^2/n\sigma_s)$$

3. $\frac{t}{z} = \frac{2.8}{a^2\sqrt{H}} \left(\frac{\sigma_s}{\sqrt{\sigma_p}}\right)$

$A = .342n^2 + (.639 \times 10^{-5})B^2(1-\frac{2}{n}) + (.907 \times 10^{-2})B$

and

$W_t = aL40.8t + (n-1)a[-.0114z^2 + 1.035z + 2.50]$

D. STIFFENERS WITH SEMI-FIXED ENDS ORIENTED PARALLEL TO THE LONG SIDE OF THE PLATE

USING SIMILAR METHODS:

1. For the plating:

$t = .179\ (a/n)\sqrt{H/\sigma_p}$

2. For the stiffeners:

$z = .064\ (HaL^2/n\sigma_s)$

3. $\frac{t}{z} = \frac{2.8}{L^2\sqrt{H}} \left(\frac{\sigma_s}{\sqrt{\sigma_p}}\right)$

$C = .342n^2 + (.639 \times 10^{-5})D^2(1-\frac{2}{n}) + (.907 \times 10^{-2})D$

and

$W_t = aL40.8t + (n-1)L[-.0114z^2 + 1.035z = 2.50]$

E. STIFFENERS WITH BRACKETED ENDS ORIENTED PARALLEL TO THE SHORT SIDE OF THE PLATE

USING SIMILAR METHODS:

1. For the plating:

$t = .179\ (L/n)\sqrt{H/\sigma_p}$

2. For the stiffeners:

Due to the addition of brackets, the maximum design moment of the stiffener becomes $M = \frac{w\ell^2}{24}$.

$\therefore \quad z = .032\ (HLa^2/n\sigma_s)$

3. $\frac{t}{z} = \frac{5.6}{a^2\sqrt{H}}(\frac{\sigma_s}{\sqrt{\sigma_p}})$

$A \doteq .342n^2 + (.157 \times 10^{-5})B\ (1-\frac{2}{n}) + (.45 \times 10^{-2})B$

and

$$W_t = aL40.8t + (n-1)a[-.0114z^2 + 1.035z + 2.50]$$
$$+ (n-1)(.173)a[-.0114z^2 + 1.035z + 2.50]$$

F. <u>STIFFENERS WITH BRACKETED ENDS ORIENTED PARALLEL TO THE LONG SIDE OF THE PLATE</u>***

<u>USING SIMILAR METHODS</u>:

1. For the plating:

$t \doteq .179\ (a/n)\sqrt{H/\sigma_p}$

2. For the stiffeners:

$z = .032\ (HaL^2/n\sigma_s)$

3. $\frac{t}{z} = \frac{5.6}{L^2\sqrt{H}}(\frac{\sigma_s}{\sqrt{\sigma_p}})$

$C = .342n^2 + (.157 \times 10^{-5})D^2(1-\frac{2}{n}) + (.45 \times 10^{-2})D$

and

$$W_t = aL40.8t + (n-1)L[-.0114z \ + 1.035z + 2.50]$$

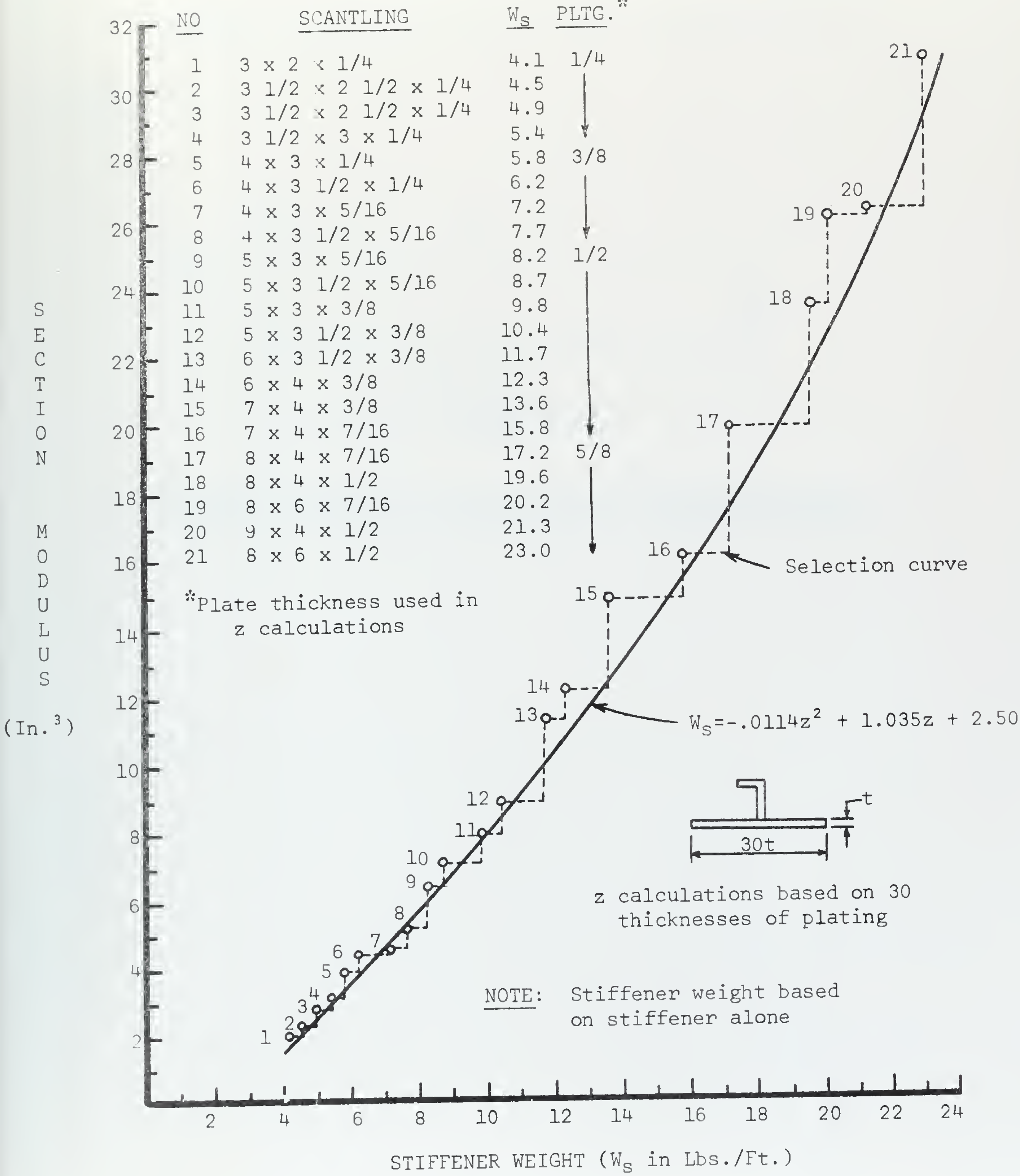
$$+ (n-1)(.173)L[-.0114z^2 + 1.035z + 2.50]$$

*The derivations in sections A and C were obtained from Reference 1.

**The equation for stiffener weight per foot as a function of stiffener section modulus came from Harlander's (Reference 1) curve fitting of a typical plot of weight per foot versus section modulus for a series of angle stiffeners. See Figure 7.

***See Appendix II.

SECTION MODULUS VERSUS STIFFENER WEIGHT (Inverted Angles)



NO	SCANTLING	W_s	PLTG.*
1	3 x 2 x 1/4	4.1	1/4
2	3 1/2 x 2 1/2 x 1/4	4.5	
3	3 1/2 x 2 1/2 x 1/4	4.9	
4	3 1/2 x 3 x 1/4	5.4	
5	4 x 3 x 1/4	5.8	3/8
6	4 x 3 1/2 x 1/4	6.2	
7	4 x 3 x 5/16	7.2	
8	4 x 3 1/2 x 5/16	7.7	
9	5 x 3 x 5/16	8.2	1/2
10	5 x 3 1/2 x 5/16	8.7	
11	5 x 3 x 3/8	9.8	
12	5 x 3 1/2 x 3/8	10.4	
13	6 x 3 1/2 x 3/8	11.7	
14	6 x 4 x 3/8	12.3	
15	7 x 4 x 3/8	13.6	
16	7 x 4 x 7/16	15.8	
17	8 x 4 x 7/16	17.2	5/8
18	8 x 4 x 1/2	19.6	
19	8 x 6 x 7/16	20.2	
20	9 x 4 x 1/2	21.3	
21	8 x 6 x 1/2	23.0	

*Plate thickness used in z calculations

Figure 7

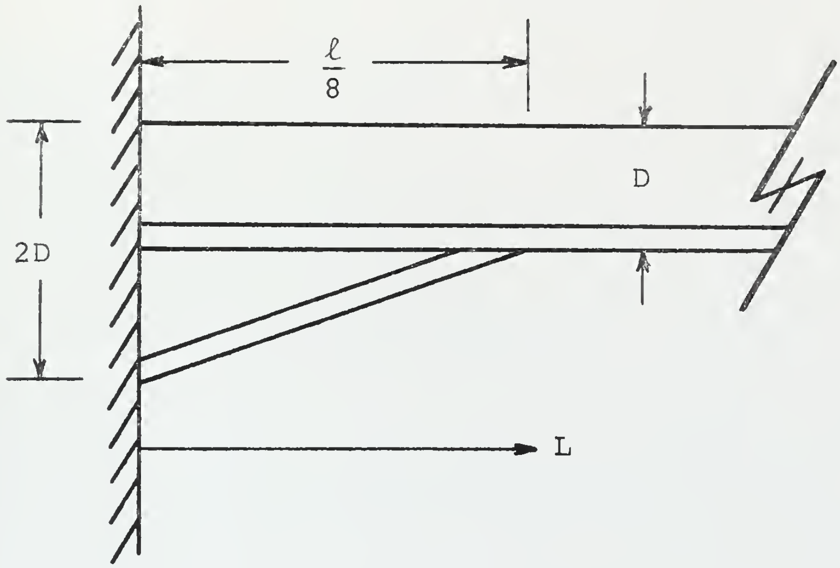
APPENDIX II

BRACKET WEIGHT AS A FUNCTION OF STIFFENER WEIGHT

APPENDIX II

BRACKET WEIGHT AS A FUNCTION OF STIFFENER WEIGHT

(Figure 8)



Assuming the standard use of bracketing cut from stiffeners (angle stiffeners) and by using weight calculations, the following relationships can be obtained:

W_b (Lbs./Ft.) = .694 W_s (Lbs./Ft.)

Two (n-1) brackets are required in each bracketed assembly.

(L/8) Ft. = length of each bracket along flange.

$\therefore$ (.173)(a)(W_s)(n-1) = weight of brackets required when stiffeners are parallel to the short side of the plate

and

$(.173)(L)(W_s)(n-1)$ = weight of brackets required when stiffeners are parallel to the long side of the plate.

APPENDIX III

COST-ESTIMATING PROCEDURE

APPENDIX III

PROCEDURE FOR ESTIMATING COST

THE METHOD USED FOR COST ESTIMATION IS THAT USED BY THE BOSTON NAVAL SHIPYARD FOR SIMILAR CONSTRUCTION*

A. MATERIAL COST (MILD STEEL):

1. For the plating:

   Cost of plating = $.10 per Lb.

2. For shaped members (stiffeners and brackets):

   Cost of shaped members = $.12 per Lb.

B. LABOR COST:

ASSUME: Weld type - simple fillet

Weld size - 1/8 In.

Condition of difficulty - normal (downhand)

Use tacking for setup

1. Procedure for hinged and semi-fixed arrangements:

   (a) Calculate feet of welding required

   (b) Multiply by .06 man-hours/Ft. to obtain man-hours welding

   (c) Multiply number of man-hours by .067 and add 1.0 to obtain man-hours required for tacking and setup

   (d) Add welding man-hours and tacking man-hours

(e) Multiply subtotal man-hours by .06 and add 1.00 for continuous jobbing and make ready allowance

(f) Add subtotal and continuous jobbing and make ready allowance for primary subtotal

(g) Multiply number of stiffeners by the length of each stiffener and that result by .02 man-hours per foot for stiffener cutting man-hours

(h) Multiply the stiffener cutting man-hours by 2 to obtain stiffener layout man-hours

(i) Multiply the perimeter of the plate by .04 man-hours per foot to obtain plate layout man-hours

(j) Multiply the cutting length of the plate by .02 man-hours per foot to obtain plate cutting man-hours

(k) Add the primary subtotal, stiffener layout man-hours, stiffener cutting man-hours, plate layout man-hours, and plate cutting man-hours to obtain the total labor man-hours required

(l) Convert this number to labor dollar and overhead dollar cost by using Table IV

2. Procedure for bracketed arrangements:

(a) Follow procedure 1 (one) to obtain total man-hours without bracket addition

(b) Calculate number of brackets required

(c) Multiply bracket number by .08 man-hours/unit to obtain man-hours for bracket welding

(d) Multiply bracket welding man-hours by .246 and add 1.0 for bracket tacking man-hours

(e) Add bracket welding and bracket tacking man-hours for subtotal bracket man-hours

(f) Multiply number of brackets by .13 man-hours per bracket for bracket fabrication allowance

(g) Add total labor man-hours (from 1 (one) above), subtotal bracket man-hours, and bracket fabrication allowance to obtain total labor man-hours

(h) Convert this number to labor dollar and overhead dollar cost by using Table IV

*Taken from Boston Naval Shipyard Standard (E); nos. 510-00-004 through 510-00-011.

TABLE IV

M.H.	C_ℓ	C_o	C_{LO}	M.H.	C_ℓ	C_o	C_{LO}	M.H.	C_ℓ	C_o	C_{LO}
1	6	5	11	41	250	221	471	81	494	437	931
2	12	11	23	42	256	227	483	82	500	443	943
3	18	16	34	43	262	232	494	83	506	448	954
4	24	22	46	44	268	238	506	84	512	454	966
5	31	27	58	45	275	243	518	85	519	459	978
6	37	32	69	46	281	248	529	86	525	464	989
7	43	38	81	47	287	254	541	87	531	470	1001
8	49	43	92	48	293	259	552	88	537	475	1012
9	55	49	104	49	299	265	564	89	543	481	1024
10	61	54	115	50	305	270	575	90	549	486	1035
11	67	59	126	51	311	275	586	91	555	491	1046
12	73	65	138	52	317	281	598	92	561	497	1058
13	79	70	149	53	323	286	609	93	567	502	1069
14	85	76	161	54	329	292	621	94	573	508	1081
15	92	81	173	55	336	297	633	95	580	513	1093
16	98	86	184	56	342	302	644	96	586	518	1104
17	104	92	196	57	348	308	656	97	592	524	1116
18	110	97	207	58	354	313	667	98	598	529	1127
19	116	103	219	59	360	319	679	99	604	535	1139
20	122	108	230	60	366	324	690	100	610	540	1150
21	128	113	241	61	372	329	701	150	915	810	1725
22	134	119	253	62	378	335	713	200	1220	1080	2300
23	140	124	264	63	384	340	724	250	1525	1350	2875
24	146	130	276	64	390	346	736	300	1830	1620	3450
25	153	135	288	65	397	351	748	350	2135	1890	4025
26	159	140	299	66	403	356	759	400	2440	2160	4600
27	165	146	311	67	409	362	771	450	2745	2430	5175
28	171	151	322	68	415	367	782	500	3050	2700	5750
29	177	157	334	69	421	373	794	550	3355	2970	6325
30	183	162	345	70	427	378	805	600	3660	3240	6900
31	189	167	356	71	433	383	816	650	3965	3510	7475
32	195	173	368	72	439	389	828	700	4270	3780	8050
33	201	178	379	73	445	394	839	750	4575	4050	8625
34	207	184	391	74	451	400	851	800	4880	4320	9200
35	214	189	403	75	458	405	863	850	5185	4590	9775
36	220	194	414	76	464	410	874	900	5490	4860	10350
37	226	200	426	77	470	416	886	950	5795	5130	10925
38	232	205	437	78	476	421	897	1000	6100	5400	11500
39	238	211	449	79	482	427	909	2000	12200	10800	23000
40	244	216	460	80	488	432	920	3000	18300	16200	34500

BOSTON NAVAL SHIPYARD PLANNING AND ESTIMATING DEPARTMENT, effective February 1971, Code 227 (A)

LABOR - \$6.10 OVERHEAD - \$5.40 TOTAL - \$11.50

APPENDIX IV

TABULAR RESULTS

TABLE I

A. HINGED-END STIFFENER/PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}
	Lbs.		In.^{3}	In.		
1.0	2427	15	8.20	.111	655	1772
1.5	1118	17	3.22	.098	384	734
2.0	672	17	1.81	.098	288	384
3.0	407	18	0.76	.093	183	224
4.0	287	18	0.43	.093	137	150

B. HINGED-END STIFFENER PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}
	Lbs.		In.^{3}	In.		
1.0	2427	15	8.20	.111	655	1772
1.5	1538	9	9.10	.124	486	1052
2.0	1128	7	8.78	.119	358	770
3.0	699	4	10.25	.140	274	425
4.0	430	3	10.24	.100	147	283

TABLE II

A. SEMI-FIXED STIFFENER/PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}
	Lbs.		In.^{3}	In.	Lbs.	Lbs.
1.0	2050	16	5.10	.104	610	1440
1.5	929	17	2.28	.098	384	545
2.0	646	18	1.14	.093	273	373
3.0	388	18	0.51	.093	183	205
4.0	280	18	0.29	.093	137	143

B. SEMI-FIXED STIFFENER/PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}
	Lbs.		In.^{3}	In.	Lbs.	Lbs.
1.0	2050	16	5.10	.104	610	1440
1.5	1282	10	5.46	.112	439	843
2.0	942	8	5.12	.104	312	630
3.0	594	5	5.46	.112	219	375
4.0	363	3	6.82	.100	147	216

TABLE III

A. FIXED-WITH-BRACKETS STIFFENER/PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}	W_b
	Lbs.		In.^{3}	In.	Lbs.	Lbs.	Lbs.
1.0	1685	16	2.56	.104	611	914	160
1.5	919	16	1.14	.104	408	440	71
2.0	642	18	0.57	.093	273	315	54
3.0	402	18	0.25	.093	182	188	32
4.0	294	18	0.14	.093	136	135	23

B. FIXED-WITH-BRACKETS STIFFENER/PLATING CHARACTERISTICS WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	Wt	n	z	t	Wp	W_{st}	W_b
	Lbs.		In.^{3}	In.	Lbs.	Lbs.	Lbs.
1.0	1685	16	2.56	.104	611	914	160
1.5	1041	12	2.48	.093	365	576	100
2.0	746	8	2.56	.104	306	375	65
3.0	472	5	2.74	.112	220	215	37
4.0	339	4	2.56	.104	153	159	27

TABLE V

A. HINGED-END STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	C_p	C_s	C_m	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	65.50	212.64	278.14	38.85	238.00	211.00	727.00	449.00
1.5	38.40	88.08	126.48	30.62	189.00	167.00	482.00	356.00
2.0	28.80	46.08	74.88	24.13	146.00	130.00	351.00	276.00
3.0	18.30	26.88	45.18	18.48	113.00	100.00	258.00	213.00
4.0	13.70	18.00	31.70	15.05	92.00	81.00	205.00	173.00

B. HINGED-END STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	C_p	C_s	C_m	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	65.50	212 64	278.14	38.85	238.00	211.00	727.00	449.00
1.5	48.60	126.24	174.84	23.27	143.00	127.00	445.00	270.00
2.0	35.80	92.40	128.20	18.40	113.00	100.00	341.00	213.00
3.0	27.40	51.00	78.40	11.16	67.00	59.00	204.00	126.00
4.0	14.70	33.96	48.66	8.70	55.00	49.00	153.00	104.00

TABLE VI

A. SEMI-FIXED STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	C_p	C_s	C_m	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	61.00	172.80	233.80	41.20	250.00	221.00	705.00	471.00
1.5	38.40	65.40	103.80	30.62	186.00	164.00	454.00	350.00
2.0	27.30	44.76	72.06	25.33	156.00	138.00	366.00	294.00
3.0	18.30	24.60	42.90	18.48	113.00	100.00	256.00	213.00
4.0	13.70	17.16	30.86	15.05	92.00	81.00	204.00	173.00

B. SEMI-FIXED STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	C_p	C_s	C_m	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	61.00	172.30	233.80	41.20	250.00	221.00	705.00	471.00
1.5	43.90	101.16	145.06	26.71	162.00	143.00	450.00	305.00
2.0	31.20	75.60	106.80	21.79	134.00	119.00	360.00	253.00
3.0	21.90	45.00	66.90	14.57	88.00	78.00	233.00	166.00
4.0	14.70	25.92	40.62	9.76	61.00	54.00	156.00	115.00

TABLE VII

A. FIXED-WITH-BRACKETS STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE SHORT SIDE OF THE PLATE

L/a	Cp	C_s	C_b	Cm	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	61.10	109.68	19.20	189.98	50.78	311.00	275.00	776.00	586.00
1.5	40.80	52.80	8.52	102.12	38.63	235.00	208.00	545.00	443.00
2.0	27.30	37.80	6.48	71.58	35.86	220.00	194.00	486.00	414.00
3.0	18.20	22.56	3.84	44.60	29.01	177.00	157.00	379.00	334.00
4.0	13.60	16.20	2.76	32.56	25.58	156.00	138.00	327.00	294.00

B. FIXED-WITH-BRACKETS STIFFENER/PLATING COST VALUES WITH STIFFENERS PARALLEL TO THE LONG SIDE OF THE PLATE

L/a	Cp	C_s	C_b	Cm	M.H.	C_ℓ	C_o	C_t	C_{LO}
	$	$	$	$	Hrs.	$	$	Nearest Dollar	$
1.0	61.10	109.68	19.20	189.98	50.78	311.00	275.00	776.00	586.00
1.5	36.50	69.12	12.00	117.62	39.10	238.00	211.00	567.00	449.00
2.0	30.60	45.00	7.80	83.40	27.63	168.00	148.00	399.00	316.00
3.0	22.00	25.80	4.44	52.24	18.97	116.00	103.00	271.00	219.00
4.0	15.30	19.08	3.24	37.62	16.04	98.00	86.00	222.00	184.00

TABLE VIII

NORMALIZED WEIGHT AND COST VALUES

Normalized on Case A, aspect ratio = 1.0;

W_t = 2427 lbs.

C_t = \$727.00

Case A

L/a	W_{tn}	C_{tn}	n-1
1.0	1.00	1.00	14
1.5	.460	.664	16
2.0	.277	.484	16
3.0	.168	.355	17
4.0	.118	.282	17

Case B

L/a	W_{tn}	C_{tn}	n-1
1.0	1.00	1.00	14
1.5	.634	.612	8
2.0	.465	.470	6
3.0	.288	.280	3
4.0	.177	.210	2

Case C

L/a	W_{tn}	C_{tn}	n-1
1.0	.845	.970	15
1.5	.383	.625	16
2.0	.266	.504	17
3.0	.160	.352	17
4.0	.116	.281	17

Case D

L/a	W_{tn}	C_{tn}	n-1
1.0	.845	.970	15
1.5	.529	.619	9
2.0	.388	.495	7
3.0	.245	.321	4
4.0	.150	.214	2

TABLE VIII (Continued)

Case E

L/a	W_{tn}	C_{tn}	n-1
1.0	.695	1.07	15
1.5	.379	.750	15
2.0	.265	.669	17
3.0	.166	.521	17
4.0	.121	.404	17

Case F

L/a	W_{tn}	C_{tn}	n-1
1.0	.695	1.07	15
1.5	.430	.780	11
2.0	.308	.549	7
3.0	.195	.373	4
4.0	.140	.305	3

SAMPLE PROBLEM

GIVEN DATA:

$L = 12.0$ ft.

$a = 4.0$ ft.

$H = 20.0$ ft.

$\sigma p = 33.0$ k.s.i.

$\sigma_s = 27.0$ k.s.i.

FOLLOW DESIGN PROCEDURE II (OVERALL OPTIMIZATION):

1. Personal preference dictates equal importance of both weight and cost. From Figure 4, by moving the 45 degree slope up and to the right, it is determined that the stiffeners should be placed parallel to the short side of the plate and should be continuous, following the semi-fixed theory.

2. From Appendix I:

$$\frac{t}{z} = \frac{2.8}{a^2\sqrt{H}} \left(\frac{s}{\sqrt{\sigma_p}}\right)$$

$$\frac{t}{z} = .184$$

3. From Appendix I:

$$A = .342n^2 + (.639 \times 10^{-5})B^2(1-\frac{2}{n}) + (.907 \times 10^{-2})B$$

where

$$A = L^2\sqrt{\frac{H}{\sigma_p}} \qquad \text{and} \qquad B = \frac{HLa^2}{\sigma_s}$$

therefore, $A = 112$

$B = 142$

substituting,

$$.342n^3 - 110.6n - .254 = 0$$

solve for closest value of n

hence, $n = 18$

4. From Appendix I:

$$t = \frac{.179\ A}{Ln} = .093 \text{ in.}$$

$$z = \frac{.093}{.184} = .505 \text{ in.}^3$$

5. Feasible value for t closest to least-weight value is $t = .125$ in.

6. $n = \dfrac{.179\ A}{tL} = \dfrac{(.179)(112)}{(.125)(12)}$

$n = 13.3$, therefore, the actual value for n is 14

7. $\dfrac{t}{z} = .184 \quad \therefore \quad z = \dfrac{.125}{.184}$

$z = .68 \text{ in.}^3$

8. From Appendix I:

$$W_t = 40.8\ aLt + (n-1)(a)[(-.0114)z^2 + 1.035z + 2.50]$$

$$W_t = 399 \text{ lbs.}$$

where $W_{st} = 154$ lbs.

and $Wp = 245$ lbs.

9. Evaluate cost by method outlined in Appendix III (self explanatory).

Thus the optimum structure in this case:

(1) $t = .125$ in.

(2) $z = .68$ in.^{3} ($W_s = 3.2 \frac{\text{lbs.}}{\text{ft.}}$)

(3) Thirteen stiffeners; semi-fixed, oriented parallel to the short side of the plate (stiffener spacing = .857 ft.)